

# Neutrino Properties

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Workshop on Intermediate Neutrino Program  
BNL, February 5, 2015

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Ben Montreal

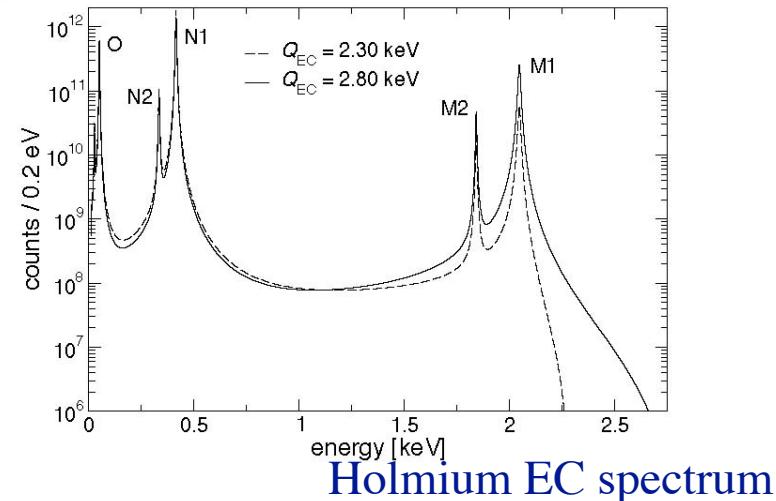
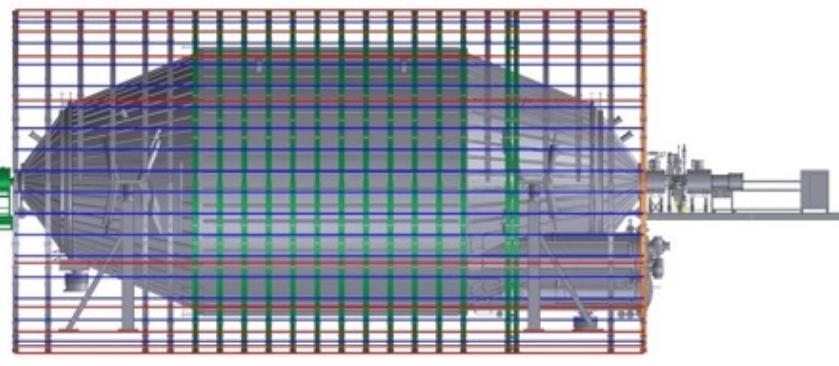
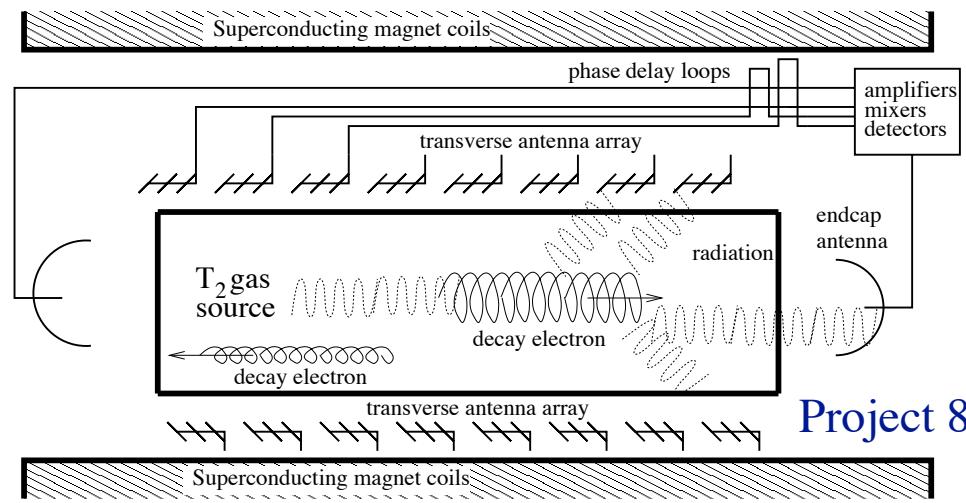
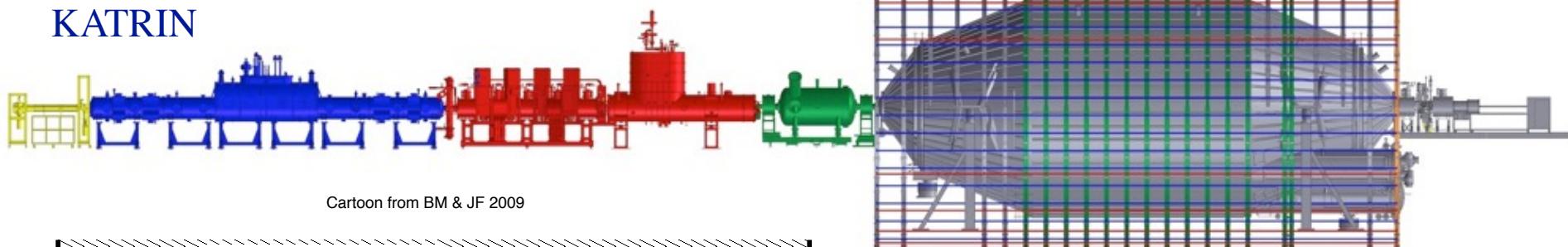
# Topics

- Neutrino mass
  - KATRIN(+upgrades), Project 8,  $\mu$ -calorimeter experiments (HOLMES, ECHO, NuMECS)
- CE $\nu$ NS, neutrino magnetic moment
  - With reactor (RICOCHET), DAR (COHERENT), source (e.g.  $^{51}\text{Cr}$ ) experiments
- Majorana/Dirac nature of neutrinos ( $0\nu\beta\beta$ )
  - CUORE, Majorana/GERDA, EXO-200/nEXO, NEXT, KamLAND-Zen/NuDot, SNO+/Theia, SuperNEMO

# Neutrino Mass

- Absolute values of the neutrino masses are among the last unknown parameters of the  $\nu$ SM

KATRIN



# KATRIN Sensitivity

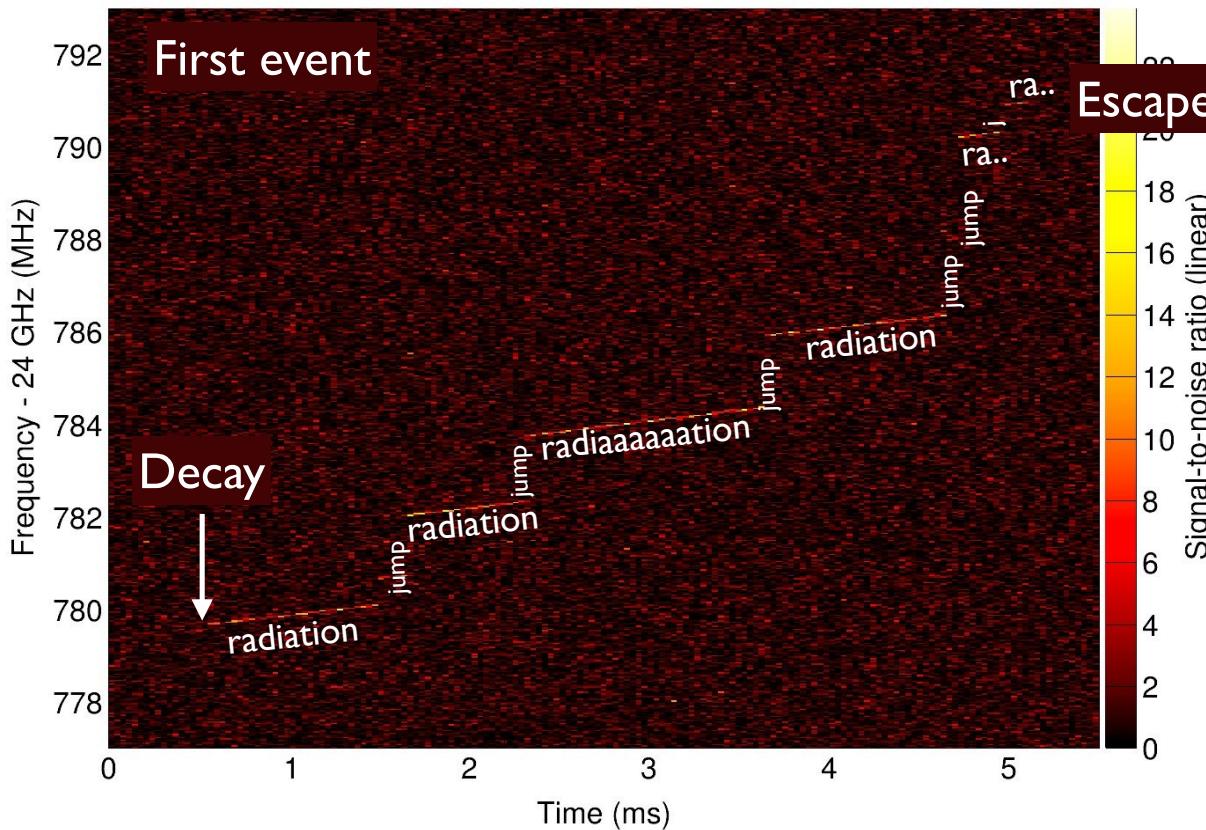
	Activity	Neutrino mass sensitivity
2015	Commissioning	
2016	Transition to tritium	~1 eV
2017	Running	0.4 eV
2018	Running	0.3 eV
2019	End of run, upgrades?	0.2 eV
2020	Upgrade runs?	

Complementary to cosmology,  $0\nu\beta\beta$

Supported in the US by DOE-NP

# Project 8

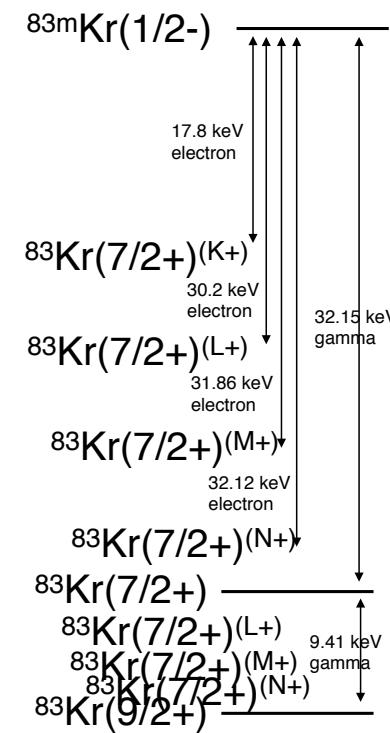
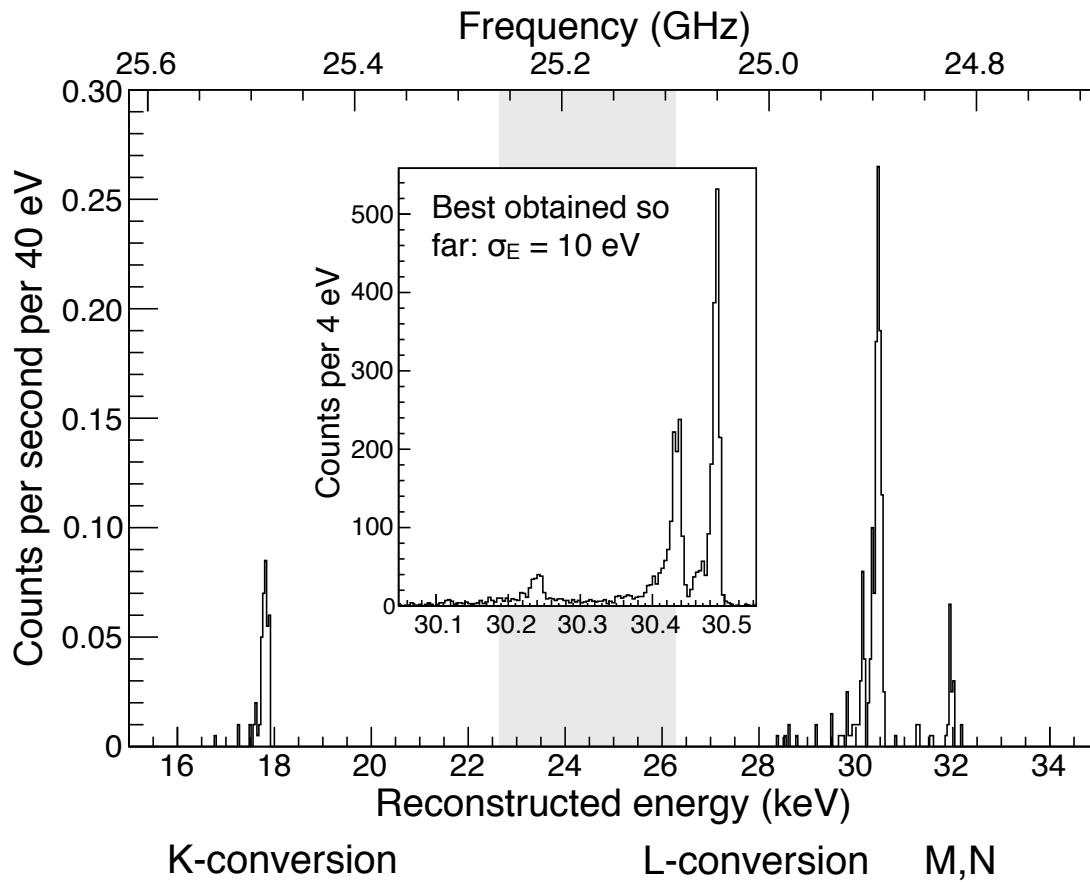
- Proof of concept available (first tracks)
  - R&D required for to demonstrate ultimate sensitivity



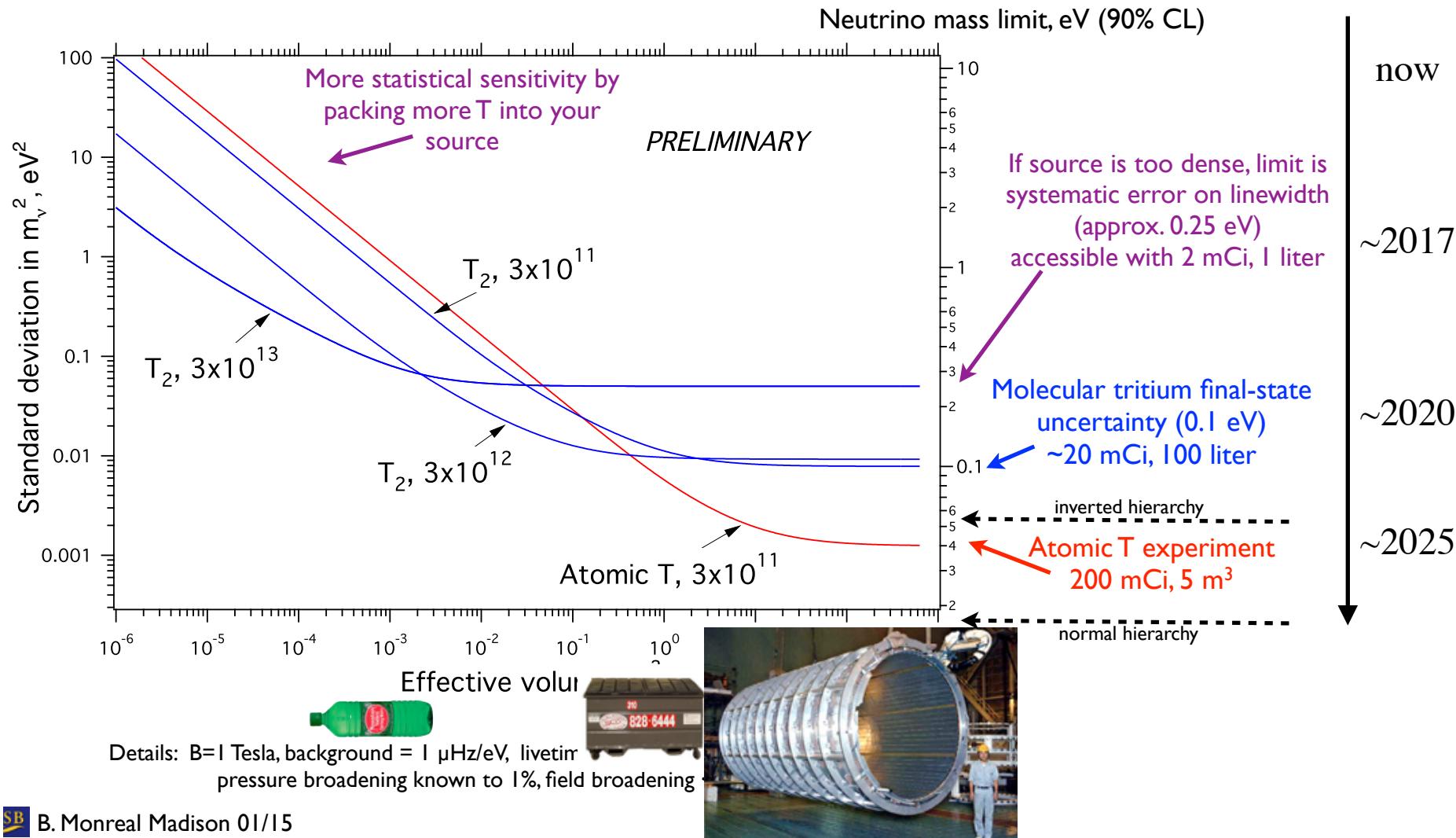
# Project 8

## $^{83m}\text{Kr}$ conversion electron spectrum

Asner et. al.,  
arXiv:1408.5362  
PRL in review



# Project 8



# Neutrino Mass: Microcalorimeters

- Understanding the decay

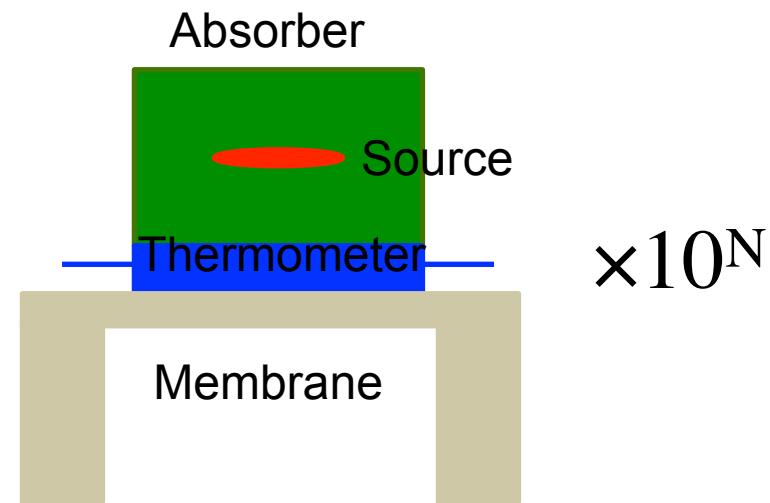
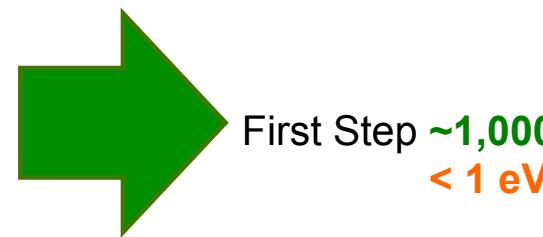
- Reaction Q-value

- Tasks to address

- Ho-163 Production
- Source Deposition
- Detector Performance

- Current efforts

- HOLMES
- ECHO
- NuMECS



First Step ~1,000 detectors  
 $< 1 \text{ eV/c}^2$  sensitivity

} ~5 years

Scalable to 10,000-100,000 detectors  
 $< 0.1 \text{ eV/c}^2$  sensitivity

} ~10 years

UNIVERSITY  
OF MIAMI

Significant R&D required: but complementarity to other DOE-HEP programs (CMB-S4)

$^{163}\text{Ho}$  can benefit from the US isotope program, common issues with other projects, e.g.  $^{51}\text{Cr}$

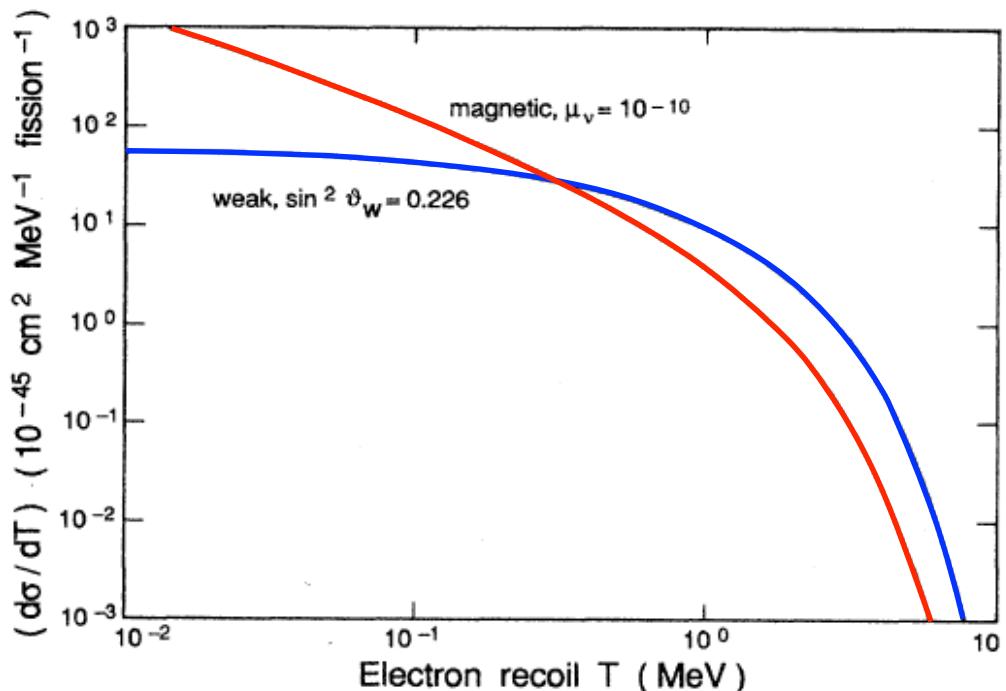
# CE $\nu$ NS and $\nu$ Magnetic Moment

## Neutrino-Electron Elastic Scattering Cross Section

Weak Part

$$\frac{d\sigma}{dT} = \frac{G_F^2 m_e}{2\pi} \left[ (g_V + g_A)^2 + (g_V - g_A)^2 \left(1 - \frac{T}{E_\nu}\right)^2 + [g_A^2 - g_V^2] \frac{m_e T}{E_\nu^2} \right] + \frac{\pi \alpha^2 \mu_\nu^2}{m_e^2} \frac{1 - T/E_\nu}{T}$$

where  $g_V = 2 \sin^2 \theta_W + \frac{1}{2}$  and  $g_A = \frac{1}{2}$  for  $\nu_e$



The E&M contribution to the elastic scattering cross section would be a consequence of a non-zero neutrino magnetic moment.

Evidence of a non-zero neutrino magnetic moment would appear as a dramatic increase in the scattering rate for the lowest energy recoil electrons.

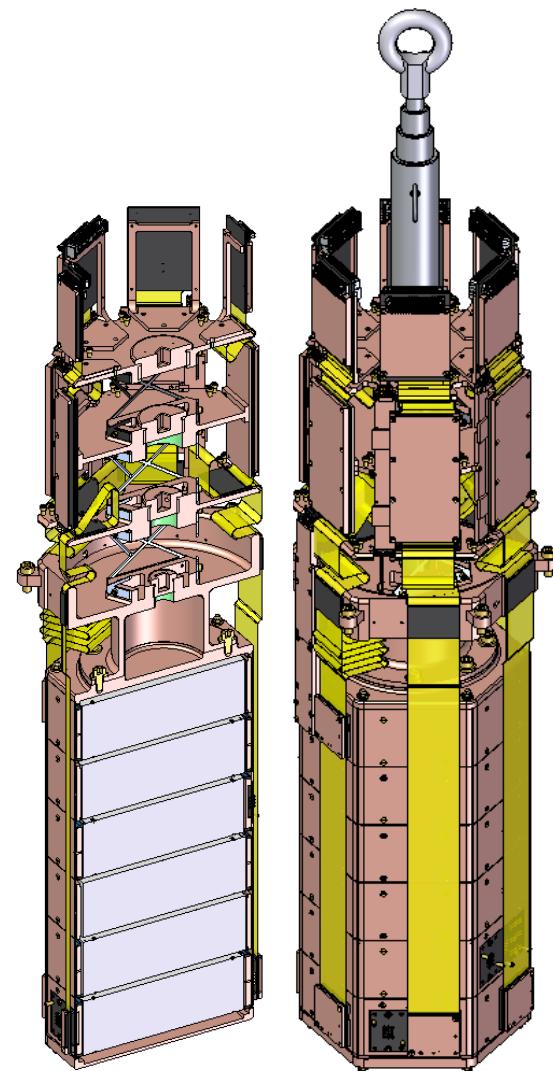
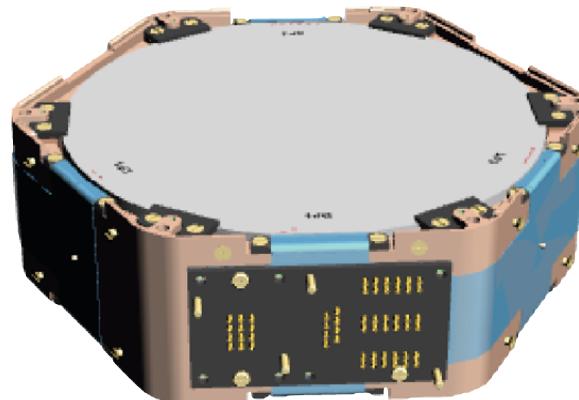
Complementarity to DM searches

# CE $\nu$ NS

- Coherent elastic Neutrino-Nucleus Scattering is a yet-unobserved process that is cleanly predicted by the Standard Model. US community is leading the effort towards the first observation of this process, which may be possible, **with relatively modest investments, in the next few years.**
- Once observed, CE $\nu$ NS could help constrain models with non-standard neutrino interactions, have sensitivity to nuclear weak charge, and would offer complementary constraints on sterile sector
  - Variety of source/detector configurations possible
    - 👉 Reactors (RICOCHET), accelerators (COHERENT, CENNS), sources ( $^{51}\text{Cr}+\text{LZ}$ )
- Program matches well to FOA parameters
  - <\$10M, results in ~5 years

# Ricochet Phase 1: SuperCDMS Tower at a Reactor

- Leverage R&D and Engineering being done by the SuperCDMS G2 Experiment.
- 1 Tower holds 6 detectors, ~100 eVnr Threshold
- 4 Si Detectors = 2.4kg Si = 11 CEvNS events per day
- 2 Ge Detectors = 2.8kg Ge = 26 CEvNS events per day
- **>7000/1000/400** events per month at the SONGS, ATR, and MIT reactors
- **>20** events per month at the SNS (for comparison)



# COHERENT @ SNS



ORNL is strongly supporting BG studies for neutrino experiment at the SNS

ORNL support: 3 LDRD's (>\$300k) + Wigner Fellow

# COHERENT @ SNS

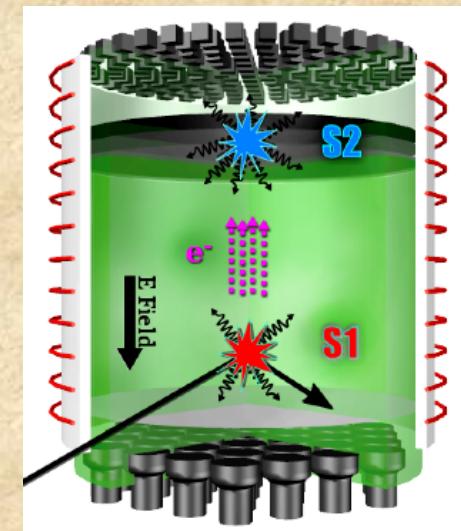
MJD prototype cryostat with 20 kg of HPGe detectors, could be available by the end of 2015



14 kg low background CsI crystal is available at the University of Chicago



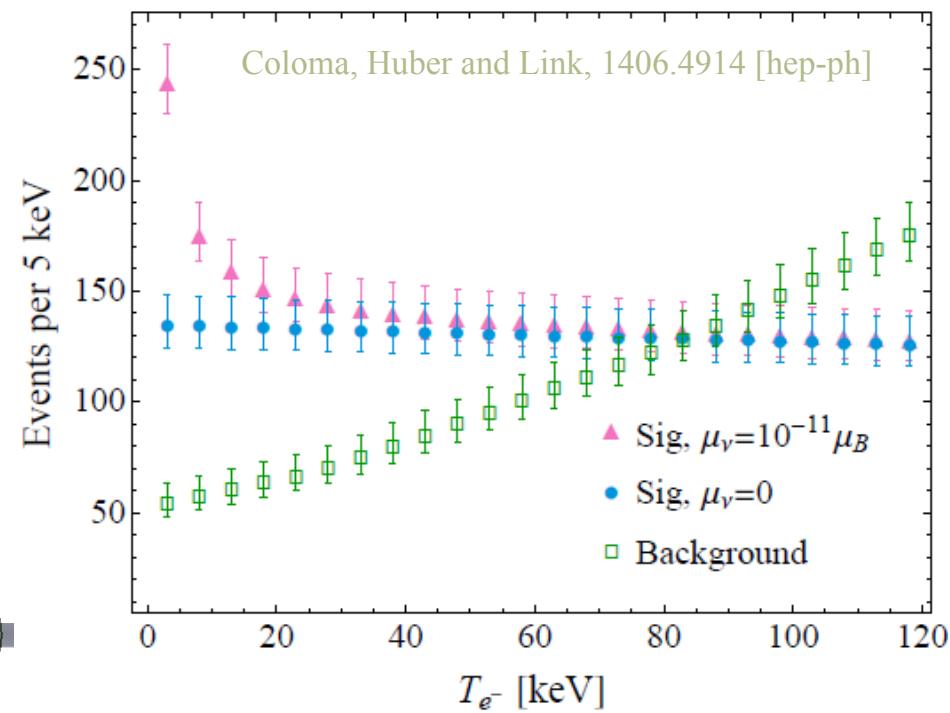
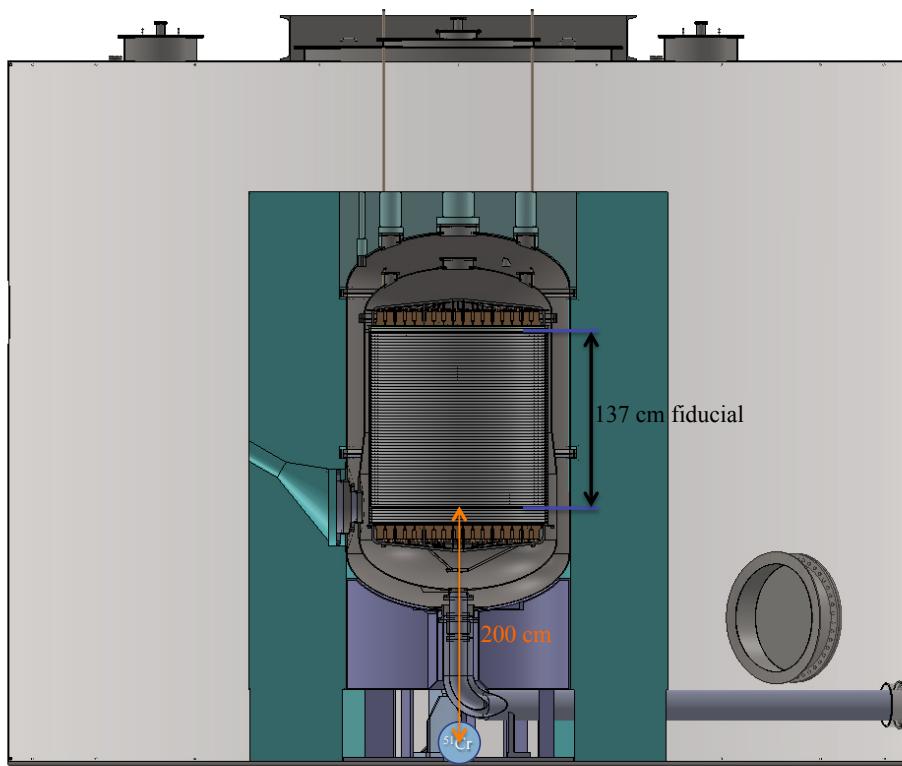
100 kg, 2 phase LXe is detector being built at MEPhI, Moscow



**15 m from the target, 100 kg detector, prompt 30 MeV neutrinos**

Target	Max Recoil (keV)	Cross section $10^{-42}\text{cm}^2$	Threshold, keV <sub>nr</sub>	N events, year
Ge	27	5830	3	2560
I	15	19400	10	732
Xe	15	22300	1	5970

# CE $\nu$ NS with $^{51}\text{Cr}$

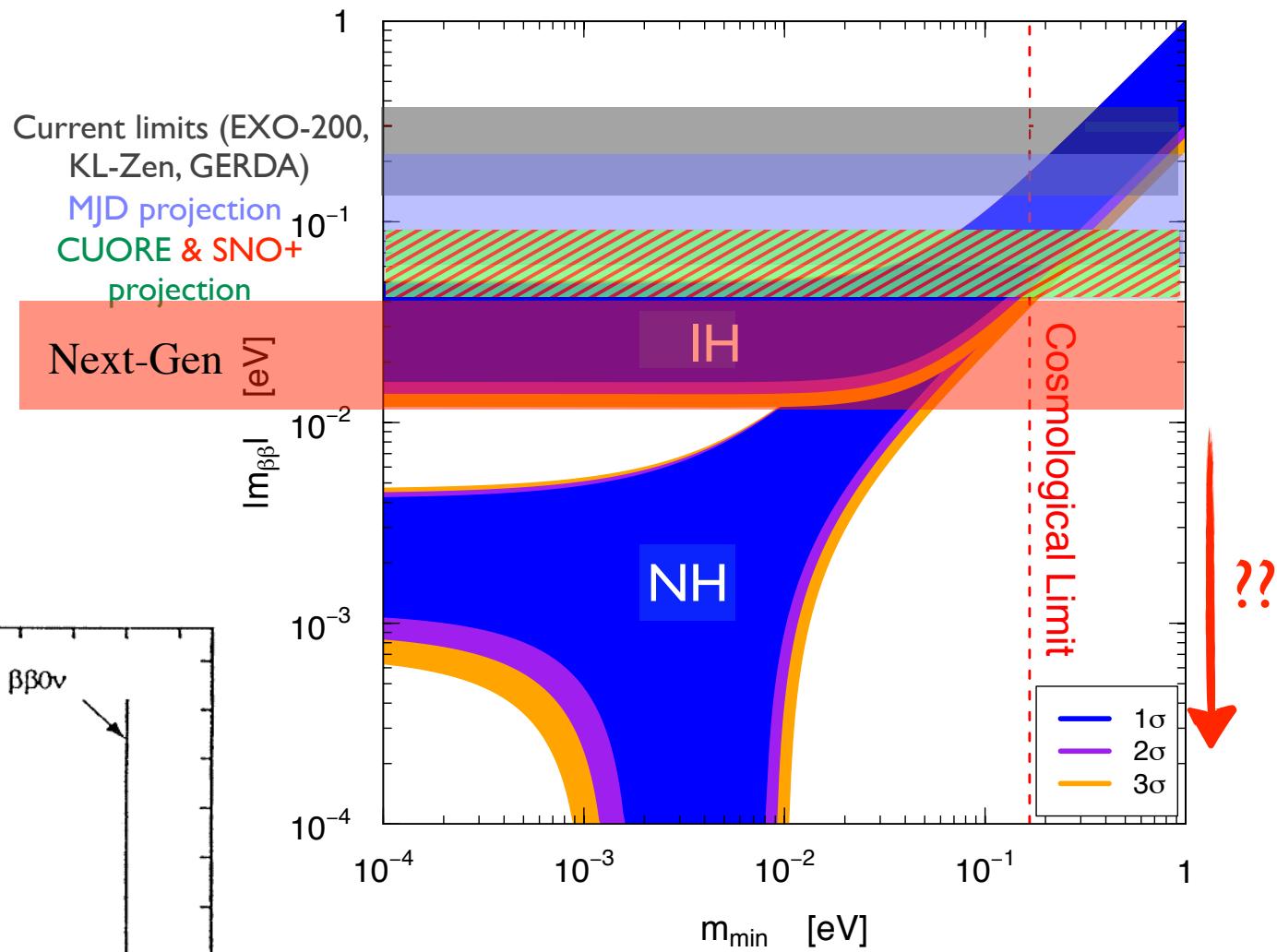
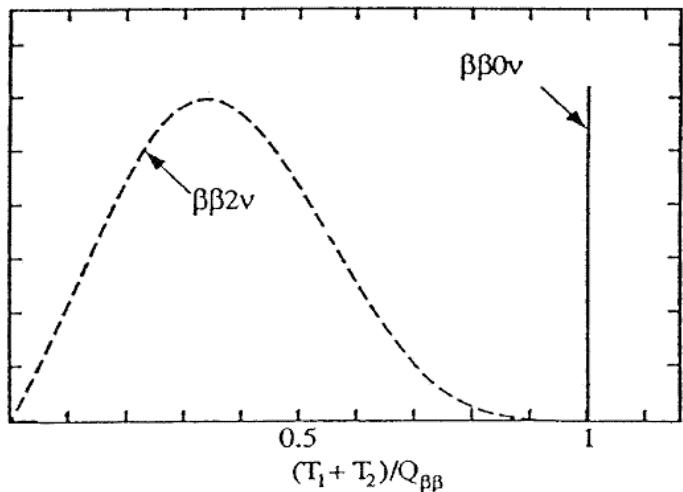
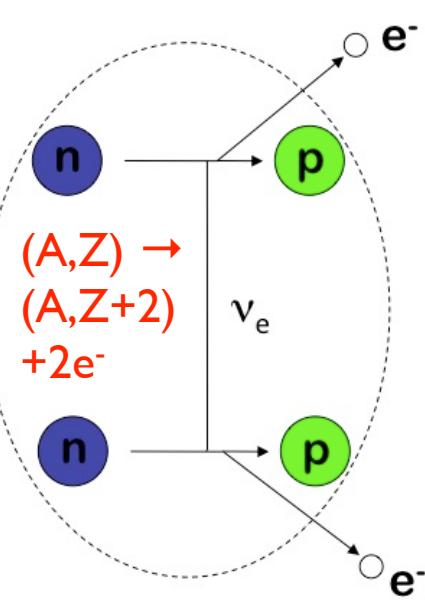


Complementarity with the sterile neutrino program (with sources)

# Neutrinoless Double-Beta Decay

- Searches for NLDBD aim to discover whether Lepton Number is a fundamental symmetry of nature or is violated, and determine Dirac or Majorana nature of neutrinos. The current generation of experiments will search for NLDBD with a sensitivity to the effective Majorana mass of order 100 meV. The next generation of experiments will aim for an order of magnitude improvement in sensitivity.

# Neutrinoless Double Beta Decay

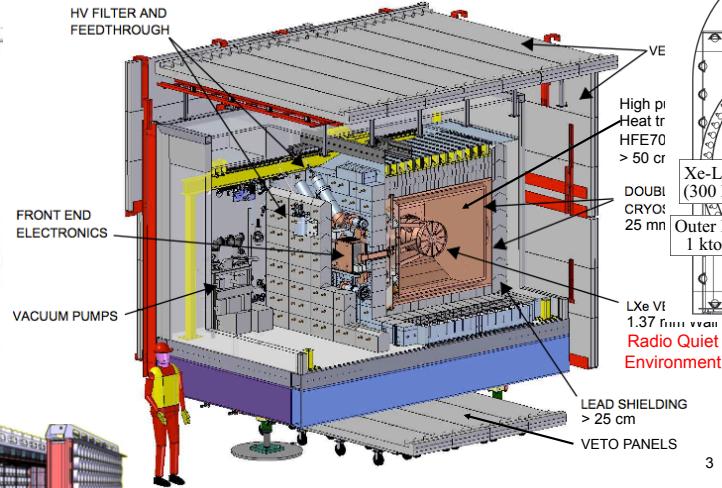
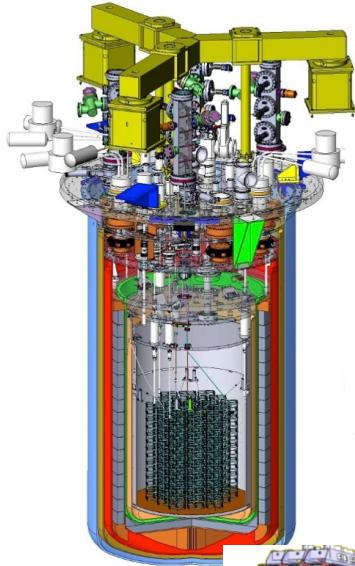


S. M. Bilenky & C. Giunti, Mod. Phys. Lett. A27, 1230015 (2012)

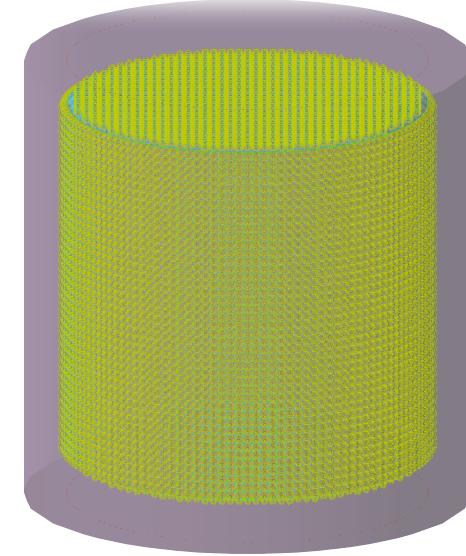
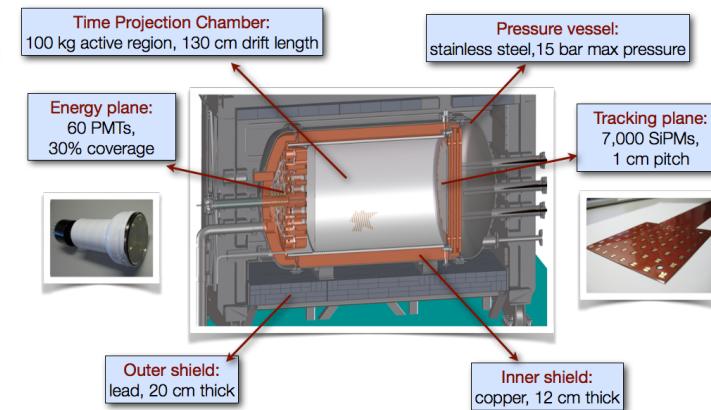
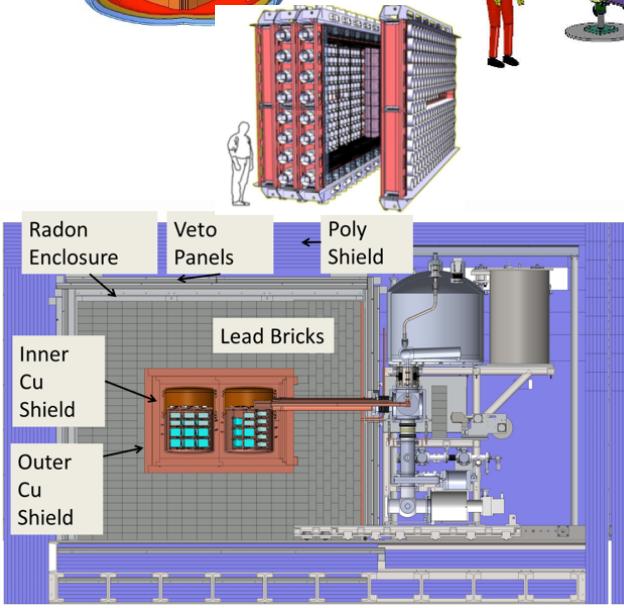
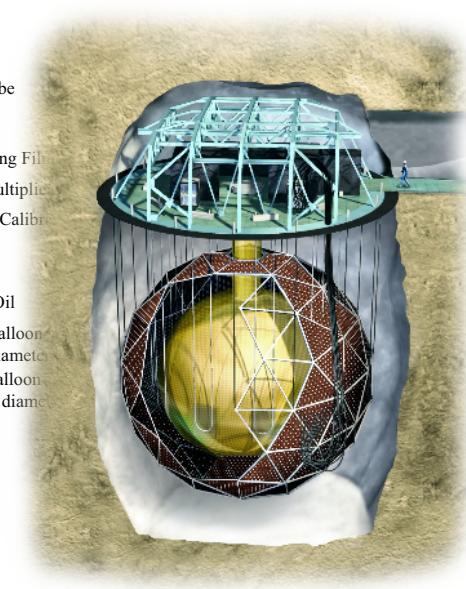
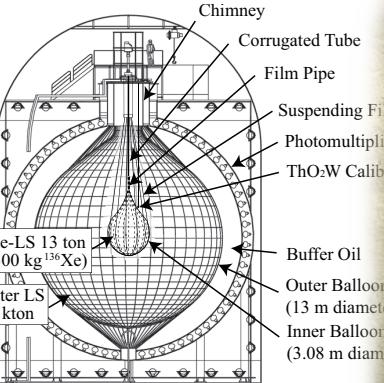
# Neutrinoless Double-Beta Decay

- There is a tremendous diversity of available techniques and detector technologies. The US community is gearing towards selecting the leading candidates for one or more next-generation experiments, shepherded by the NSAC-NLDBD committee. A targeted program of R&D activities towards mature concepts of the next-generation experiment is one of the priorities identified by this committee.

# O $\nu\beta\beta$ Experiments



3



# Some Common R&D Issues

- Liquid noble gases: general need for reliable high-voltage design principles. EXO (!) NEXT (?), in common with dark matter and long baselines.
  - Experience of "things that work on test stand but spark when installed."
- Low-background everything
  - Copper (Majorana, CUORE), cabling (MJD)
  - New and complex scintillators (Kamland-Zen, SNO+, Theia, NuDot) and matched photosensors (fast? cheap? red-sensitive?)